CEBAF PROPOSAL COVER SHEET

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CEBAF
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Newport News, VA 23606

and received on or before OCTOBER 30, 1989

TITLE: SHADOWING OF REAL PHOTONS IN NUCLEI: MEASUREMENT OF THE TOTAL HADRONIC CROSS SECTION

CONTACT PERSON: Daniel I. Sober

ADDRESS, PHONE AND BITNET:
Physics Department, Catholic University
Washington, DC 20064 Phone (202)635-5856
BITNET: SOBER@CUA

THIS PROPOSAL IS BASED ON A PREVIOUSLY SUBMITTED LETTER OF INTENT

- [x] YES
- [ ] NO

IF YES, TITLE OF PREVIOUSLY SUBMITTED LETTER OF INTENT

SHADOWING OF REAL PHOTONS IN NUCLEI: MEASUREMENT OF THE TOTAL HADRONIC CROSS SECTION

ATTACH A SEPARATE PAGE LISTING ALL COLLABORATION MEMBERS AND THEIR INSTITUTIONS

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contact: Sober

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List of collaboration members:

The Catholic University of America, Washington, DC 20064

D. I. Sober (contact person)	SOBER@CUA
Hall Crannell	CRANNELL@CUA
J. T. O'Brien	OBRIENJ@CUA

Arizona State University, Tempe, AZ 85287

R. O. Alarcon	ALARCON@ASUCPS
J. R. Comfort	COMFORT@ASUCPS
B. G. Ritchie	RITCHIE@ASUCPS

Carnegie-Mellon University, Pittsburgh, PA 15213

R. Schumacher	REINHARD@CMPHYSME

CEBAF, Newport News, VA 23606

B. Mecking	MECKING@CEBAFVAX
R. R. Whitney	WHITNEY@CEBAFVAX

George Washington University, Washington, DC 20052

B. Berman	BERMAN@GWUVM
W. J. Briscoe	MP0WJB@GWUVM
K. S. Dhuga	
L. Maximon	
A. Mokhtari	
M. F. Taragin	MFT00117@GWUVM
D. Zubanov	

University of Illinois, Champaign IL 61820

R. M. Laszewski	LASZEWSKI@UIUCNPL

University of South Carolina, Columbia, SC 29208

G. S. Blanpied	N530022@UNIVSCVM
B. M. Preedom	N530005@UNIVSCVM
C. Djalali	N530048@UNIVSCVM

University of Virginia, Charlottesville, VA 22901

S. T. Thornton	STT@VIRGINIA

Virginia Polytechnic Inst. and State Univ., Blacksburg, VA 24061

D. A. Jenkins	JENKINS@VTVM2

Proposal to CEBAF -- October 1989

SHADOWING OF REAL PHOTONS IN NUCLEI: MEASUREMENT OF THE TOTAL HADRONIC CROSS SECTION

D. I. Sober (contact person), Hall Crannell and J. T. O'Brien
The Catholic University of America, Washington, DC 20064

R. O. Alarcon, J. R. Comfort and B. G. Ritchie
Arizona State University, Tempe, AZ 85287

R. Schumacher
Carnegie-Mellon University, Pittsburgh, PA 15213

B. Mecking and R. R. Whitney
CEBAF, Newport News, VA 23606

B. Berman, W. J. Briscoe, K. S. Dhuga, L. Maximon, A. Mokhtari, M. F. Taragin and D. Zubanov
George Washington University, Washington, DC 20052

R. M. Laszewski
University of Illinois, Champaign IL 61820

G. S. Blanpied, B. M. Preedom and C. Djalali
University of South Carolina, Columbia, SC 29208

S. T. Thornton
University of Virginia, Charlottesville, VA 22901

D. A. Jenkins
VPI&SU, Blacksburg, VA 24061

We propose to measure the energy and A-dependence of the total hadronic cross section for real photons between 0.5 and 3.0 GeV in the CEBAF Large Acceptance Spectrometer (CLAS) by detecting all charged outgoing hadrons produced by tagged photons on nuclear targets (Be, C, O, Al, Cu, Sn, Pb). Measurements on hydrogen and deuterium targets will also be made for calibration. The distribution of neutrons will be sampled with the CLAS trigger counters, and the spectra of π^os will be measured with thin lead converters inserted between the drift chambers. Corrections for missing solid angle, detection thresholds and neutrals will be made using Monte Carlo calculations constrained by the data. This experiment will fill a major gap in the existing total cross section data, and clarify the transition from isobar production to shadowing and vector meson dominance. Data taken in this experiment will also be extremely useful for checking the calculations of trigger rates and backgrounds for other experiments using the CLAS.

1. INTRODUCTION

The electromagnetic interaction has long been valued as a credible and sensitive probe of the properties of hadrons and nuclei because of the weakness of the interaction, the structurelessness of the photon (except for the "vacuum polarization" effects of virtual electron pairs) and the completeness of the theory of quantum electrodynamics. With the advent of multi-GeV physics, however, it became apparent that, as a result of hadronic contributions to the vacuum polarization, the photon has an internal structure similar to that of the hadrons, but occurring with a relative probability of order 1/137 [We74; Ba78].

At high energies the interactions of photons with nuclei become increasingly similar to the interactions of hadrons with nuclei. In particular, both hadron and photon interactions exhibit the phenomenon of "shadowing" (Figure 1): i.e. the projectile is most likely to have its initial interaction with a nucleon on the incident side of the nucleus. If the photon interacts only "weakly", it should have equal probability of interacting with any nucleon in the nucleus, leading to a cross section proportional to the mass number A. If, however, the photon converts to a hadron state which persists over a finite distance, it cannot interact with a nucleon lying deep in the nucleus without first interacting with other nucleons in its path. In the extreme limit of this case, the interaction becomes a surface effect, varying approximately as $A^{2/3}$. Shadowing in nuclei for any process is usually expressed in terms of the effective nucleon number,

$$A_{eff}/A = \sigma_{\gamma A}/[Z\ \sigma_{\gamma p} + (A-Z)\ \sigma_{\gamma n}]\ .$$

In the absence of shadowing, A_{eff}/A would be equal to unity for all mass numbers A, while for complete surface absorption A_{eff}/A would be proportional to $A^{-1/3}$.

The total photon hadronic cross section on complex nuclei, $\sigma_{\gamma A}$, is a fundamental quantity in any discussion of the hadronic properties of the photon. At high energies it should exhibit the shadowing phenomenon described above. By means of sum rules, $\sigma_{\gamma A}$ can be related to the electromagnetic polarizability of the bound nucleon [Ba88, Ha89], a quantity which has been much discussed in the context of the EMC effect.

Measurements of $\sigma_{\gamma A}$ have been performed over a wide range of energies (10 MeV to 185 GeV) by a variety of techniques. A summary of the existing data is given in [Ah85], and many of the experiments above 2 GeV are described in more detail in [Ba78]. Below pion threshold, the cross sections for diffferent nuclei exhibit large nuclear-structure-dependent differences. In contrast, in the $\Delta(1232)$-resonance region the cross section per nucleon $\sigma_{\gamma A}/A$ is, within experimental uncertainties, independent of A for nuclei between beryllium and uranium but substantially different from $\sigma_{\gamma N}$ on a free nucleon, an effect which has been attributed to the existence of the N-Δ system inside the nucleus. Between 2 GeV and 20 GeV, where the shadowing mechanism described above should appear, the data show an A-dependence like $A^{0.91}$[We74]. The vector dominance model (VDM) [Ge61] fits the qualitative features of the data, but predicts too much shadowing. Some results are shown in Figure 2.

The greatest deficiency in the data is in the upper part of the resonance region, between 0.5 and 2.0 GeV (Figure 3), which is covered only by a few data points from Yerevan [Ar83] and Cornell [Mi77]. The data are too sparse and imprecise to show whether the higher isobars appear in the nuclear total cross section, or whether there is a consistent dependence on the mass number A [Ah85]. These energies are particularly interesting because they are just at the transition to the region where shadowing begins [Ba78].

In addition to the intrinsic interest in the measurement of $\sigma_{\gamma A}$, this experiment will provide an excellent "tune-up" for the CLAS, allowing it to be used under relatively low-stress conditions. The use of a tagged photon beam avoids many of the background problems arising from the presence of an electron beam, and the performance of the CLAS as a hadron detector can be tested without the complications accompanying the high electron rate in an (e,e'X) experiment. With low tagged photon rates and a simple trigger, we can accumulate calibration data on timing and particle identification which are not critical for most phases of the present experiment. In addition to providing data on the total cross section, the particle distributions accumulated in this experiment will become part of the permanent data base used in Monte Carlo calculations to estimate the trigger rates and backgrounds to be expected in measurements of complicated multi-particle processes in the CLAS.

2. EXPERIMENT

We propose an experiment to provide data on the photon total hadronic cross section on a series of nuclei (Be, C, O, Al, Cu, Sn, Pb) in the energy region 0.5 to 3.0 GeV by using the CLAS in conjunction with the tagged photon beam. The trigger will be the least restrictive possible: any particle (other than an electron or positron) identified in the CLAS trigger counters, in coincidence with a tagged photon. Forward-angle electrons and positrons will normally exit through the forward hole in the CLAS without being detected; wide-angle electrons and positrons up to 45 degrees will be rejected by the forward shower counter, and the very small contribution at larger angles can be easily estimated and subtracted.

Corrections must be made to the data for several effects:
(1) Loss of charged particles due to finite solid angle (particles emitted extremely forward, extremely backward, or into the toroid coils).

(2) Loss of charged particles, especially protons, due to detection threshold in the drift chambers and counters.
(3) Events in which all the final-state particles are neutrals.

If the properties of the final states which are primarily responsible for these losses are reasonably well understood, the losses due to effects (1)-(3) can be calculated by the use of an intranuclear-cascade Monte Carlo calculation, which can then be calibrated by comparing its predictions with specific observable final states. Such a technique was used successfully by the Bonn group in its measurements in the 200-400 MeV region [Ar81]. Measurements of the total cross section at higher energies [Mi77, Ar83, many others cited in Ba78] generally use a non-selective hadron calorimeter which surrounds the target and extends to very forward angles. The present experiment is a hybrid of the two techniques: the presence of multi-particle final states requires a fuller solid angle coverage than the Bonn experiment, but the ability to identify the most important final-state topologies and fit the data to extrapolate for the missing acceptance makes it possible to perform a good measurement despite the incomplete solid angle acceptance of the CLAS.

In the energy range of the proposed experiment, the magnitudes of the detection inefficiencies can be estimated in advance from the measurements of photoproduction made in the early 1970's using the SLAC-LBL 82-inch hydrogen bubble chamber and laser-backscattered quasi-monoenergetic photons of 1.4, 2.8 and 4.7 GeV [Ba72]. Figure 4 shows the γp topological cross sections in this energy region, classified according to the number of charged-particle "prongs", as well as the total cross section $\sigma_{\gamma p}$. For photon energies above 1.5 GeV, the cross section is predominantly due to events producing three or more charged particles, which can be detected with high efficiency in the CLAS. Acceptance corrections will predominantly affect those events in the "one-prong" category, which includes the two-body final states π^+n and $\pi^\circ p$. Figure 5 shows γp total cross sections for specific final states, mostly extracted from the same data set.

Much less is known about the multiparticle final states from photoreactions with neutrons. Deuterium bubble chamber photoproduction data exist for 4.3 GeV laser-backscattered photons [Ei76], 4.3 GeV annihilation photons [Ei72], and untagged 5.5 GeV bremsstrahlung [Be74]. There appears to be little difference between the charged-particle multiplicities of γn and γp reactions in this energy region, with only 6.8 μb attributed to 0-prong events from the neutron at 4.3 GeV [Ei76]. In another reference [Ga74], it is reported that photoabsorption events in nuclei with only neutral hadrons produced make up less than 2% of the total hadronic cross section from 2 to 4 GeV.

From these data we can see that the corrections (1)-(3) are an appreciable fraction of the total cross section only below about 1.5 GeV. In this lower-energy region, a large fraction of the total cross section is due to the well-studied two-body photoproduction processes on single nucleons, $\gamma N \rightarrow \pi N$, for which existing multipole analyses [Ar82, Cr83] can be used to predict and fit the kinematic variation of the cross sections. Above 1 GeV, where the single-pion production reactions begin to decline in significance, the next dominant process is $\gamma N \rightarrow \pi^+ \pi^- N$ via ρ° photoproduction, whose cross section from both neutrons and protons has been extensively studied [Ba78]. Thus the most important elementary reactions which are needed for the intranuclear-cascade Monte Carlo calculation are already reasonably well known.

Direct confirmation of the Monte Carlo corrections can be made by detecting neutral particles, albeit with low efficiency. The 5-cm-thick trigger counters of the CLAS are expected to have an efficiency of approximately 5% for energetic neutrons and can thus be used to measure the neutron energy (via time of flight) and angular distributions. If the counters in the final design are too thin, then a row of thick plastic scintillators outside the CLAS, extending from forward to backward angles in a thin region of azimuth, could be used to measure the neutron rate versus polar angle. Suitable neutron counters are already available from the George Washington University and University of Virginia groups.

The angular and energy distribution of photons resulting from π° decay can be measured by placing thin (approximately 0.25 radiation length, e.g. 1.4 mm of lead) converters between the first and second drift chamber superlayers of one or more sectors of the CLAS for part of the running time. The absence of a track in the first chamber indicates that a photon had entered the converter, and the measurement of the electron and positron tracks in the outer chambers will give a good determination of the photon's energy and direction. It would be most desirable to instrument all 6 sectors in this way, as this would allow detection and reconstruction of π° mesons with about 5% efficiency, providing a very significant handle on the many-particle final states, and serving as an excellent pilot experiment for more detailed measurements of π° production which are being proposed. Taking data both with and without the photon converter will allow a detailed analysis of the effects of such a converter on the detection of the charged particles.

These measurements of neutron and photon distributions, and particularly the comparison of purely neutral events with neutral-charged coincidences, are an important part of the experiment. When used with the Monte Carlo, they will considerably enhance the reliability of the corrections. Extrapolating from the experience of the Bonn group at lower energies [Ar81], we expect that a systematic error of a few percent can be obtained for the total hadronic cross section.

A further improvement to the experiment can be made by also measuring the total photoproduction cross section from hydrogen and deuterium targets. Measurements on these processes in this energy region are more complete and more consistent than the measurements on heavier nuclei[Ba78], but the errors are still in the range of several percent. A new measurement under the same conditions as the measurement on complex nuclei will provide a useful calibration and allow a more direct determination of the shadowing factor.

3. REQUIREMENTS

a) Incident beams

Electron energies of 2.0 and 3.6 GeV.

Tagged photon beam capable of tagging photons of between 0.2 E_0 and 0.9 E_0, at a rate of 10^6/sec, with energy resolution better than 0.01 E_0. The low tagging rate is desirable because of the very loose trigger requirements.

b) Targets

Approximately 1 g/cm^2 targets of Be, C, O (water or BeO), Al, Cu, Sn and Pb. No special target handling required.

Liquid hydrogen and deuterium targets, 14 cm long by 5 cm diameter if available. Otherwise 1 g/cm^2 CH_2 and CD_2 targets.

c) Run time

For 1% statistical error in the charged-particle rate for each 25-MeV photon energy bin from 500 to 3000 MeV, and with the following assumptions:

total cross section per nucleon = 100-200 μb/A
solid angle coverage per charged particle = 70%
charged-particle fraction > 70%
target thickness = 1 g/cm^2
tagged photon rate = 1×10^6 / sec,
0.5 GeV to 1.2 GeV at E_0 = 2.0 GeV
1.0 GeV to 3.0 GeV at E_0 = 3.6 GeV

we estimate the run time, including tuneup and target changes, to be:

charged-particle measurements	240 hours
photon and π^0 measurements	160 hours
Total	400 hours

These times are arrived at as follows: The main experiment would require approximately 10 hours per target at each of 2 electron energies. The target thickness and tagged photon rate have been chosen to adjust the maximum trigger rate to approximately 50 events per second (a factor of two below the 100 Hz rate estimate in the February 1989 report to PAC III.) The total beam time for 9 targets is 180 hours. With tuneup time and the time necessary to change targets, a realistic estimate of beam time would be 240 hours.

External neutron counters, if desired, would be used concurrently with these runs.

The measurement of the photon spectrum requires additional setup and running time. A thin (0.25-radiation-length) lead converter plate will be installed between the first and second superlayers of drift chambers in at least one sector (preferably in all). The sum of cross sections for π°-producing reactions is always at least 20 $\mu b/A$. The solid angle times efficiency for detecting a π° is approximately $0.7^2 \times 0.20^2 = 0.02$, so an additional 12 hours per energy per target would provide at least 10,000 fully reconstructed π°s, and about 7 times as many single-photon events, per setting. We propose doing this for H, D, C, Cu and Pb targets, adding a total of 120 hours plus setup and target changes, or 160 hours total.

d) Additional equipment

Lead converters for photon detection in CLAS.

4. MANPOWER

The collaborators listed on this proposal are all members of the tagged photon subgroup of the CLAS collaboration, and intend to spend a major part of their research effort over the next 4 years in the construction and commisioning of the tagged photon facility which is an essential part of this experiment. As CEBAF turn-on approaches, additional manpower in the form of graduate students and post-doctoral research associates will become available to the project.

The experiment is intended to be part of the initial experimental program of the CLAS collaboration, and will have the participation of other members of the collaboration whose names are not listed here.

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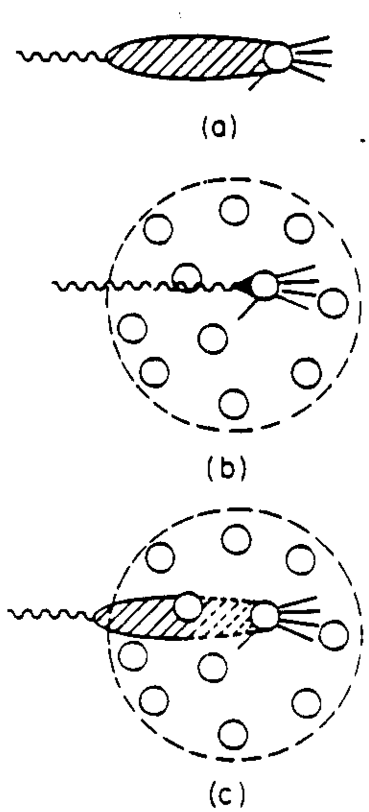
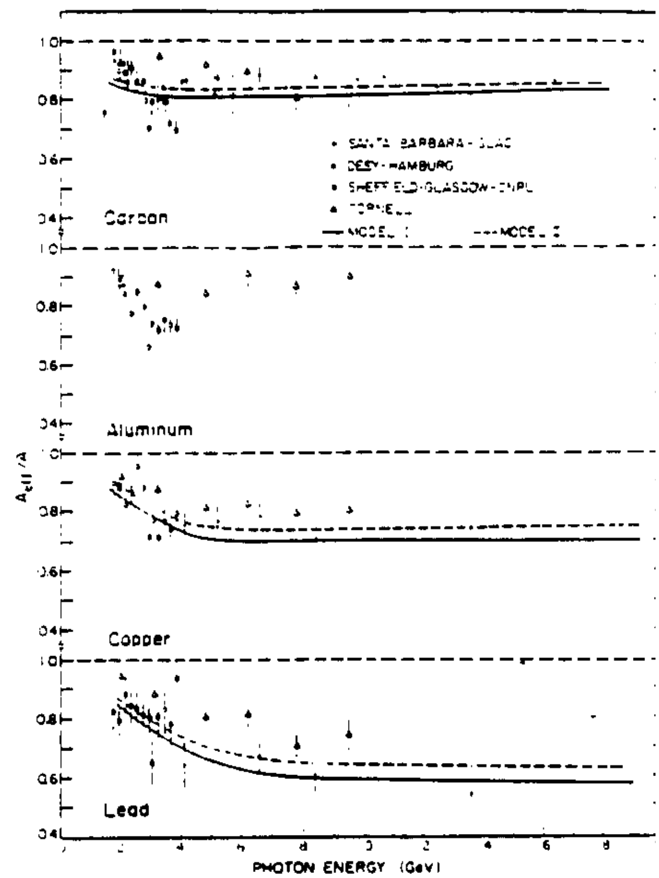


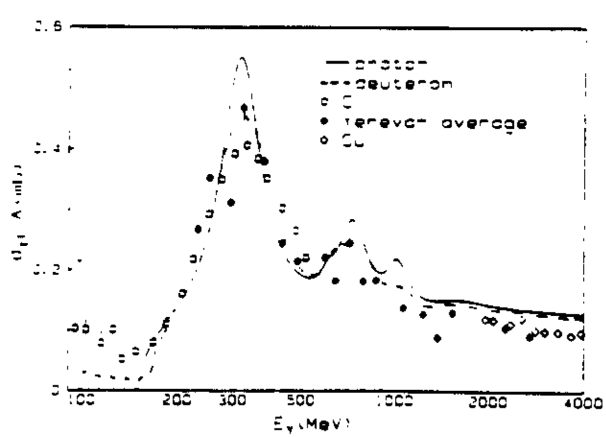
Spatial visualization of photon interactions. (a) In nteraction with a single nucleon the photon may convert to adrons a long distance before reaching the nucleon. (b) The irect interaction of a photon with a nucleon in a nucleus. This would lead to no shadowing of photons. (c) With a long ormation time, a photon cannot interact with a nucleon deep within the nucleus without initiating a reaction on another nucleon first. Thus the total cross section is reduced relative o that due to (b).

Fig. 1 (from Ba78)

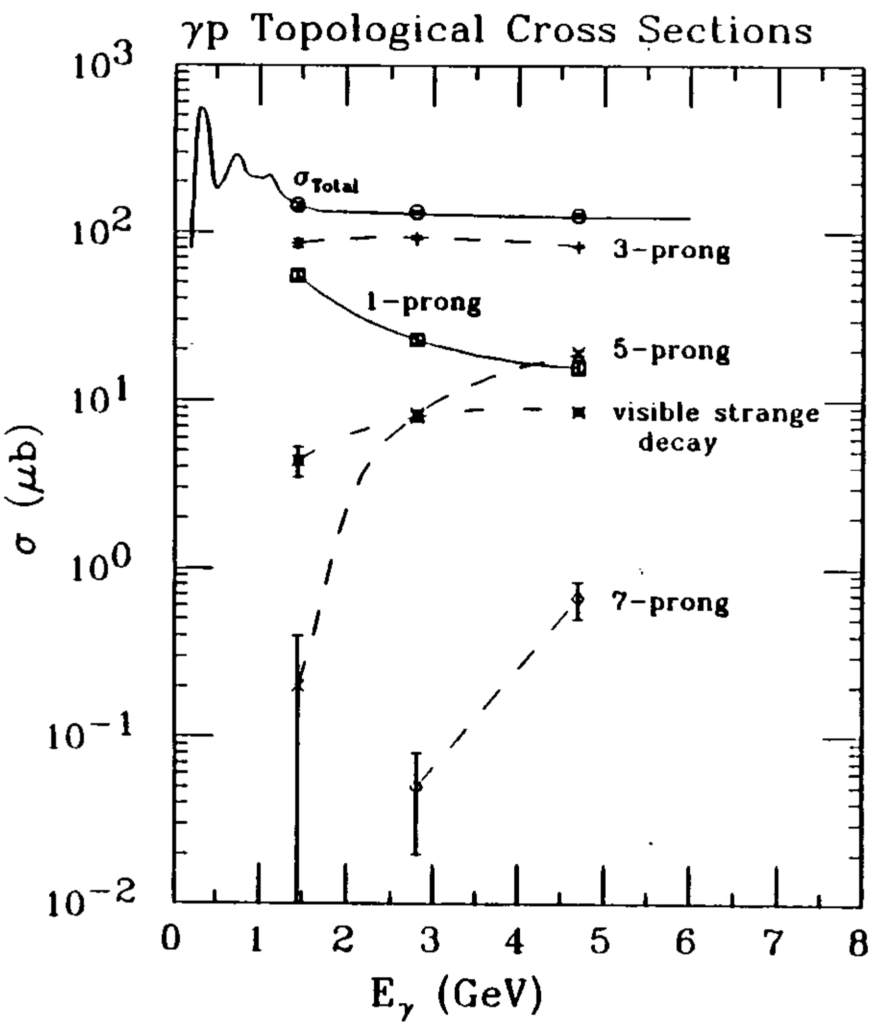


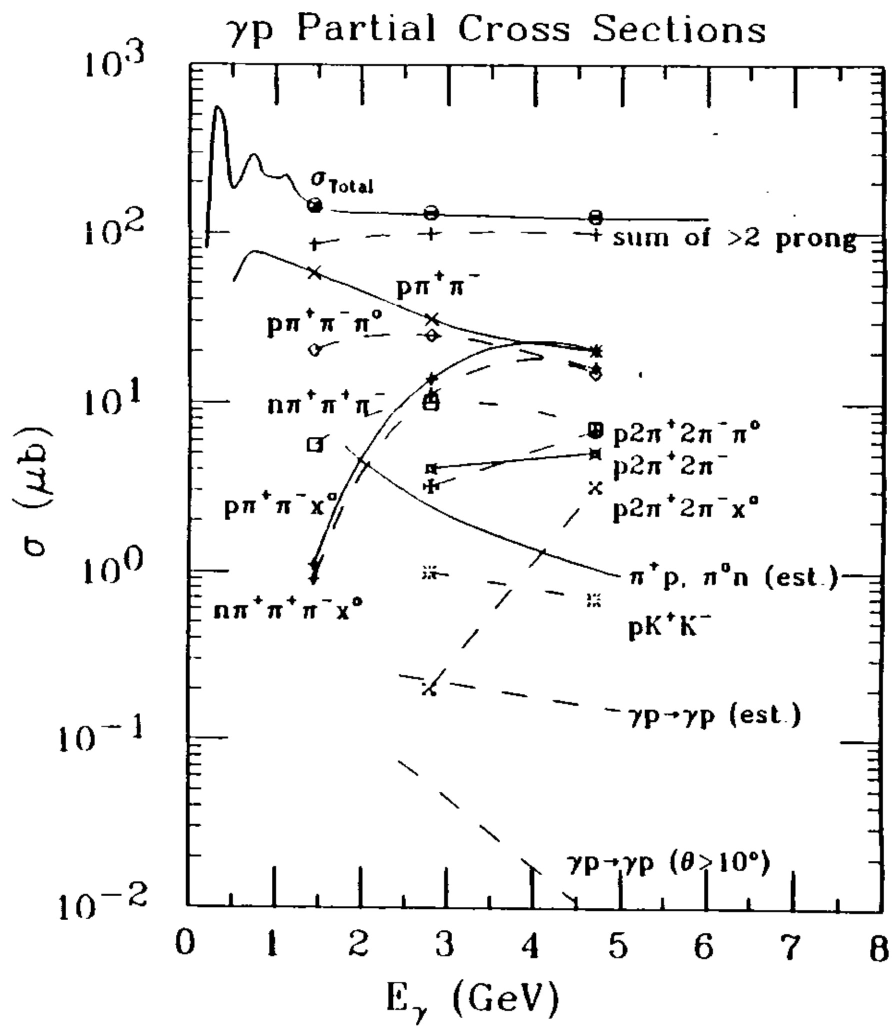
A plot of A_{eff}/A for C, Al, Cu, and Pb from measurements by the DESY–Hamburg, Glasgow–Sheffield–DNPI Santa Barbara–SLAC, and Cornell groups.

Fig. 2 (from Ba78. The theoretica curves are described in th paper.)



Cross sections in the isobar resonances region.





<u>Figure 4</u> Topological cross sections for γp at 1.44, 2.8 and 4.7 Mev, from bubble chamber measurements of [Ba72]. The γp total cross section curve is estimated from the data in [Ba78].

<u>Figure 5</u> Cross sections for specific final states in γp reactions at 1.44, 2.8 and 4.7 MeV, mostly from [Ba72]. The $\gamma p \to \pi^- n$ cross section is estimated from [Bu66], and the Compton cross section from [Bu71].